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# $O_i$ and $C_s$ Impurities Study on the Edge of Si-mc Ingot for Photovoltaic Applications

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**Abstract** The objective of this work is determining the substitutional carbon ([$C_s$]) and interstitial oxygen ([$O_i$]) concentrations in the edge of the multicrystalline silicon ingot (mc-Si) for photovoltaic applications obtained by the heat exchanger method (HEM). Some calculations of [$C_s$] and [$O_i$] was obtain by the Fourier Transform InfraRed spectroscopy (FTIR). The results obtained for [$C_s$] give an increase of bottom-up of the ingot: 130 ppm to 150 ppm. The results obtained for the [$O_i$] give constant concentrations throughout the edge of the ingot with an author of concentration 325 ppm.

**Keywords** Crystallization, mc-Si, HEM, FTIR, [$C_s$], [$O_i$]

## 1. Introduction

Global demand on photovoltaic modules is known as a surge in recent years. The majority of modules are made from multicrystalline silicon (mc-si) that dominate the world market in relation to other types of silicon with a share of about 60% (Muller 2007), the heat exchanger method (HEM) is a compromised method used for the solidification of ingots of mc-si.

The concentration of impurities plays a very important role in the quality of silicon and therefore to the solar cell quality produced from it. Among the contaminants found in silicon is cited the substitutional carbon ($C_s$) and the interstitial oxygen ($O_i$), which from certain concentrations begin to reduce in a remarkable way the lifetime of minority charge carriers and following the reduction in diffusion lengths, which results in a decrease of the performance of solar cells (Bothe 2005 et Amzil 1983).

## 2. Experimental

In this work we studied the board of mc-si ingot solidified in CRTSE (UDTS) by HEM technique, which produces ingots of mc-si (p type with a resistance of 1.2 ohm-cm$^{-1}$ ) of 80 Kg and a square section of 44x44 cm$^2$. This ingot was divided into briquets of a square section of 10x10 cm$^2$ and thickness of plates of about 300 microns.

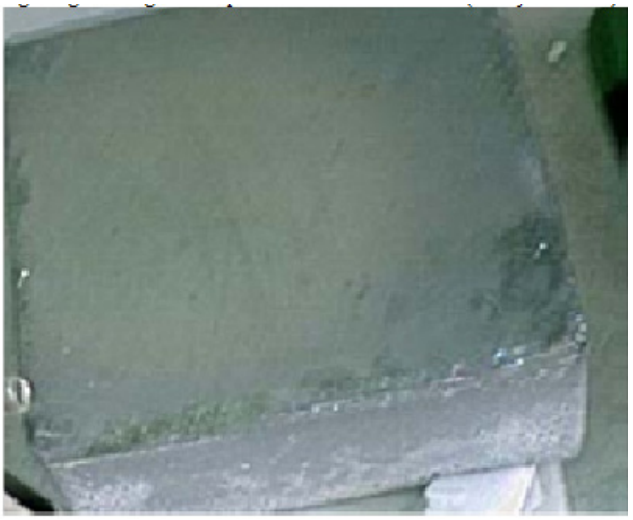

**Figure 1.** Ingot 80 Kg and a square section of 44x44 cm$^2$ (Ouadjaout 2005)

The [$O_i$] and [$C_s$] were measured by a Thermo Nicolet NEXUS 670 FTIR spectrometer, the features of this instrument and measurement conditions are as follows: The spectrum range is the medium Infrared range (MIR).

Number of sweeps: 32 sweeps, Resolution: 4 (1.928cm$^{-1}$), separator: KBr Detector: DTGS KBr.

The collection and treatment of FTIR spectra for calculation of [$C_s$] and [$O_i$] has been obtain using the Omnic software.

## 3. Results and Discussion

Figure 2 shows the positioning of $C_s$ and $O_i$ peaks in a spectrum of an ingot edge sample of mc-si obtained at room temperature (RT).

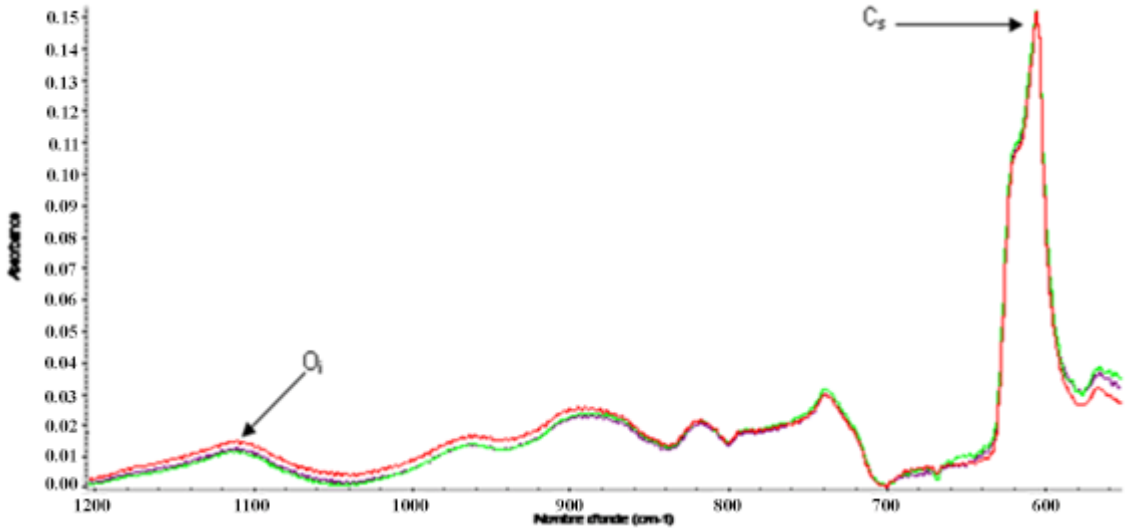


**Figure 2.** FTIR spectrum of a sample

For quantification of $O_i$ and $C_s$ we used the carbon uptake and oxygen peaks at 609 $cm^{-1}$ and 1107 $cm^{-1}$, respectively (PIVAC 1989) and the following relationship:

$$N = \mathrm{K}\ \mathrm{x}\nu, \quad \text{avec} \quad K = \frac{1}{\mathrm{d}}\ln(T_{\max}/T_{\min}).$$

with:

d : The thickness of the sample in cm.

$T_{max}$: The absorption mod peak

$T_{min}$: The value of the base line of the peak in absorption mod.

$\nu$ : The Conversion factor

for $O_i$ : $\nu_O = 2.45 \text{ x } 10^{17} cm^{-2}$

and for $C_s$: $\nu_C = 1.1 \text{ x } 10^{17}\ cm^{-2}$

### 3.1. Study of [$O_i$] at the Edge of the Ingot mc-Si

Figure. 3 shows the vertical distribution of concentration $O_i$ throughout the multicrystalline silicon ingot edge.

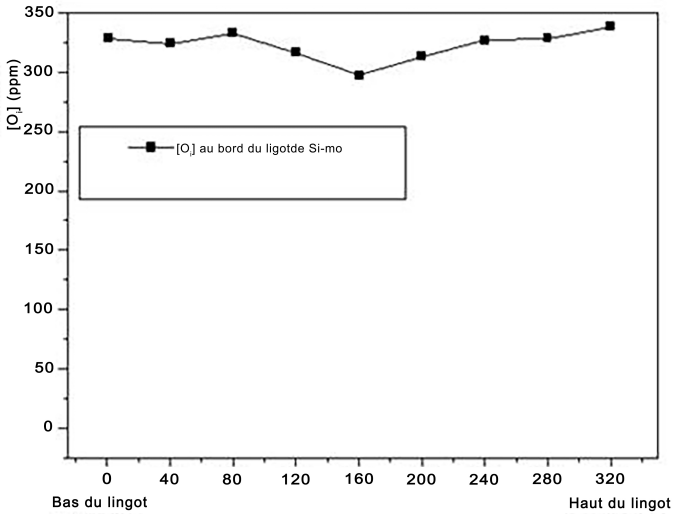


**Figure 3.** Vertical Distribution Profile of [$O_i$] in the edge of the mc-Si ingot at $T_A$

The results of the FTIR showed a constant concentration of the interstitial oxygen $O_i$ i the edge of mc-Si ingot with an average of about 325 ppm. This value is high compared to the tolerant level of oxygen (Xi 2007). This high concentration of ($O_i$) on the edge of the ingot may be primarily due to contamination by the crucible due to low coating and since the latter itself is already contaminated with oxygen before crystallization, other studies are underway to confirm the actual source of contamination ingots.

### 3.2. Study of [$C_s$] at the Edge of the mc-si Ingot

Figure 4 shows the vertical distribution of concentrations of $C_s$ throughout the multicrystalline silicon ingot edge.

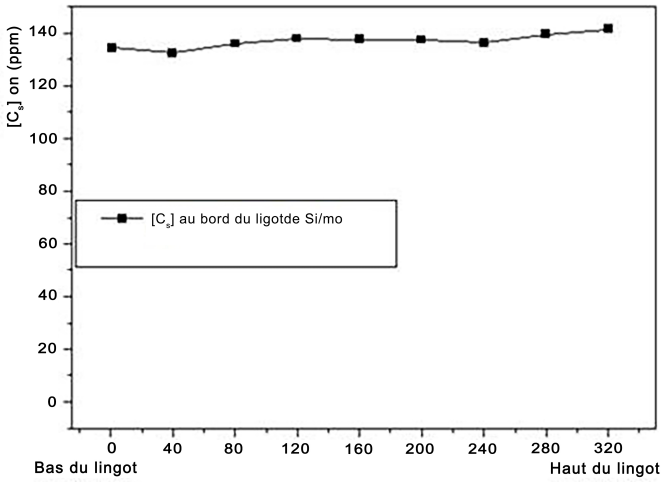


**Figure 4.** Vertical distribution profile of [$C_s$] in the edge of mc-si ingot at $T_A$

The calculation of [$C_s$] requires the presence of a cryostat, in the absence of this last one used the deconvolution method

for the separation of overlap of two peaks located at 607 $cm^{-1}$ (the first of $C_s$ and the second due to vibration of Si-Si).

FTIR results provide an average concentration of $C_s$ in the range of 150 ppm at the edge of the silicon ingot, this value is high compared tolerant rate of $C_s$ in the silicon (Kvande 2005).

## 4. Conclusions

In this work we calculated the concentrations of interstitial oxygen ($O_i$) and the substitutional carbon ($C_s$) at the edge of mc-si ingot crystallized in CRTSE. We traced the distribution profiles of these elements ($C_s$ and $O_i$) from the FTIR spectra. FTIR results show a high concentration in this region by the two impurities with an average concentration of about 325 ppm (1.6 x 1019$cm^{-3}$) of $O_i$, and 140 ppm (7.0 x 1018$cm^{-3}$) $C_s$. The calculations of [$O_i$] give accurate values, but against those of [$C_s$] it is not accurate because of overlap located at 609 $cm^{-1}$ between the peak of $C_s$ and vibration peak of Si-Si. The precise measurements of carbon concentrations require the presence of a cryostat to go at low temperatures and separate the overlap of the two peaks located at 609 $cm^{-1}$.

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